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Associations between the living environment and sleep through the mediation of the physical activity: a systematic review

Maëlle Scouvemont[1*], Catherine Elsen[2], Valériane Tannoia[2], Gwendoline Schaff[2], Stéphane Adam[3], Christina Schmidt[4], Nikita Beliy[4] and Olivier Bruyère[1]

Abstract

Objective To review the role of physical activity as a mediator in the association between the living environment and sleep.

Materials and methods Observational and experimental studies in English were included regardless of participants' age, gender, or ethnicity. Searches were conducted in Medline (via PuMed), Scopus and Embase, supplemented by manual searches. Study selection was performed by two independent reviewers on the basis of titles, abstracts, and full-text articles. Data extraction and quality assessment (using JBI critical appraisal tools) were also carried out by two reviewers. The PRISMA 2020 guidelines were followed throughout.

Results After removing duplicates, 1147 studies were screened, of which 5 studies (4 cross-sectional and 1 longitudinal) met the inclusion criteria. These studies were of moderate methodological quality. Improved access to recreational facilities was indirectly associated with longer sleep duration, lower risk of wake after sleep onset (WASO) and later wake time through increased physical activity. Strengthened neighborhood social cohesion, and reduced neighborhood violence and problems (i.e., noise, lack of access to shops and parks, litter, etc.) were indirectly associated with longer sleep duration, a lower risk of short sleep duration and better sleep quality through increased physical activity.

Conclusion Physical activity appears to be a potential promising mediator between the living environment and sleep, but evidence remains limited due to the small number of studies on this topic. Future studies using a rigorous mediation methodology and including household-level factors are needed.

Trial registration Prospero [ID: CRD42024580376].

Keywords Living environment, Sleep, Physical activity, Mediation

*Correspondence:
Maëlle Scouvemont
maelle.scouvemont@uliege.be
[1]Research Unit in Public Health, Epidemiology and Health Economics, Department of Public Health, Faculty of Medicine, University of Liège, Avenue Hippocrate 13, B23, Liège 4000 , Belgium
[2]Inter'Act Lab, ArGEnCo Department, Faculty of Applied Sciences, University of Liège, Allée de la Découverte 9, B52/3, Liège 4000 , Belgium
[3]Psychology of Aging Unit, Department of Psychology, Faculty of Psychology, Logopaedics and Educational Sciences, University of Liège, Place des Orateurs 1, B33, Liège 4000, Belgium
[4]Sleep & Chronobiology Lab, GIGA-CRC Human Imaging Research Unit, GIGA Institute, Faculty of Psychology, Logopaedics and Educational Sciences, University of Liège, Allée du 6 Août 8, B30, Liège 4000 , Belgium

Background

Sleep health is essential for maintaining both physical and mental functions [1], notably through its preventive role against a range of chronic diseases, including coronary heart disease [2, 3], cognitive decline [4], diabetes [2, 3] and anxiety [5]. Among the various factors influencing sleep, the living environment (both the dwelling and the neighborhood) has emerged as playing a significant role [6, 7]. However, the relationships between the living environment and sleep are complex and cannot be adequately understood through a straightforward analysis of an independent variable's effect on a dependent one. As a result, mediation analyses have been used to explore various causal pathways [8, 9]. In this vein, three main pathways have been identified to explain how the living environment may impact sleep [10, 11].

The first pathway, which is also the most extensively studied pathway [10], is related to ambient hazards and physical exposures. Factors such as indoor and outdoor artificial light [6, 12], neighborhood noise [12], road, rail and air traffic [6, 12], and room temperature and humidity [10, 12] all stem from an individual's living environment and, in turn, affect sleep. A focused narrative review has already been conducted on this topic, specifically targeting older people [12]. Therefore, this falls outside the scope of this systematic review.

The other two pathways are psychosocial factors and physical activity [10, 11]. Regarding the psychosocial factors, although some aspects of the social environment, such as safety, crime, and social cohesion, can influence mood, anxiety, and stress, which in turn can contribute to an inability to sleep [6], this mediator is beyond the scope of this study. Indeed, we chose to focus on a modifiable risk factor [13] in order to provide practical targets for public health interventions. For this reason, this systematic review focuses exclusively on physical activity as a mediator, rather than on psychosocial factors.

First of all, physical activity has been identified as a mediator because several environmental factors, such as neighborhood walkability, crime-related safety, the presence of sidewalks, the availability and accessibility of sports facilities or public transit, neighborhood aesthetics, and street lighting have been identified as influencing physical activity levels [14, 15]. Moreover, physical activity has been identified as a key factor affecting sleep [16, 17]. A literature review highlighted its role in reducing chronic insomnia (often treated in combination with cognitive-behavioral therapy) [17] as well as in reducing obstructive sleep apnea [16]. These beneficial effects can be explained through two strong evidence mechanisms [17]. First, engaging in physical activity increases body core temperature, which triggers thermoregulation to lower body temperature, and this decrease promotes sleep onset [17]. Second, increased physical activity boosts the levels of brain-derived neurotrophic factor (BDNF), which enhances mood and, in turn, contributes to improved sleep quality [17].

We can therefore assume that elements of the living environment, such as the walkability of the neighborhood, access to sports facilities, neighborhood aesthetics and street lighting, may be indirectly associated with sleep health through the influence of physical activity. Although this mediating pathway has been explored in several studies, no review has yet exhaustively synthesized the existing evidence on this topic. However, identifying which living environment factors influence sleep through the mediation of physical activity is essential for developing effective public health, housing, and territory planning strategies. Highlighting the role of physical activity in this association could support targeted interventions to improve both sleep health and, more broadly, overall health status. Therefore, the aim of this systematic review was to obtain a comprehensive understanding of the role of physical activity as a mediator variable in the association between the living environment and sleep.

Methods

The systematic review protocol has been published in PROSPERO with the following ID: CRD42024580376. The guidelines of "The Preferred Reporting Items for Systematic reviews and Meta-Analyses 2020" (PRISMA) [18] were followed to conduct this study, and the associated checklist was also used. The research question of the systematic review can be summarized via the following PICOs: Population = humans regardless of age, gender or ethnicity – Intervention = the association between the living environment and sleep through physical activity - Comparator = not applicable – Outcome = sleep – Study designs = both experimental and observational studies.

Literature search

The literature search was carried out in 3 databases: (1) Medline (via PubMed), (2) Scopus and (3) Embase. To obtain the most exhaustive research, both controlled language (MeSH terms in Medline and Emtree terms in Embase) and free text were used to formulate the search equations (except in Scopus, where there is no controlled language). In addition, each search equation was adapted to the specifics of each database (the three equations are provided respectively in Additional files 1, 2 and 3). We focused the search on studies available from the inception of the datasets until the 17th of July, 2024. Finally, additional manual searches (principles of snowballing) [19] were conducted on the basis of the articles included in the systematic review.

Definitions of terms

This systematic review focuses on three variables: living environment, sleep and physical activity; thus, it is essential to define each concept.

The living environment is a very broad concept, but in this study both elements related to the dwelling (private indoor and outdoor space [20]) and the neighborhood were included. Each element of the physical environment was considered, i.e. elements such as sidewalks, housing, green spaces, temperature or noise [6, 10, 21]. Additionally, factors of the social environment, including safety, criminality, stigmatization, violence and social cohesion/fragmentation, have been considered [6]. However, within the scope of this definition, we have considered only elements of the residential environment. As a result, we did not include nursing homes, hospitals, or elements related to the workplace or schools.

Regarding sleep, we considered different measures associated with sleep health including total sleep time, the total repartition time of each stage of sleep (stage 1, stage 2, slow-wave sleep (SWS), rapid eye movement (REM) sleep), sleep efficiency (ratio of total sleep time to time spent in bed), sleep latency (time transition from wake to sleep), wake after sleep onset (WASO) and nap duration and frequency [22, 23].

Finally, the concept of physical activity refers to the definition by the WHO as "*any bodily movement produced by skeletal muscles that requires energy expenditures*" [24]. In this study, all types of activities, including leisure activities, household activities, transport-related activities and work-related activities, were considered. Also, all intensity levels of physical activity, including light, moderate and vigorous were included.

Mediation frameworks

A simple mediation model (see Fig. 1) describes a causal relationship in which an independent variable (denoted as "X") affects a dependent variable ("Y") through a mediating variable ("M") [8, 25]. To confirm the presence of a mediational effect, it is essential that both the relationship between the independent variable (i.e., the living environment) and the mediator (i.e., physical activity) (Path a) and the relationship between the mediator (i.e., physical activity) and the dependent variable (i.e., sleep) (Path b) are statistically significant [25, 26].

However, the traditional Baron & Kenny approach, also known as the causal step method [27, 28], requires two additional steps beyond these significance tests to establish mediation, particularly to identify full mediation [25]. The third step requires validating the significant relationship between X and Y (Path c), which represents the total effect. The fourth step is Path c' (direct effect), which requires that the previously significant relationship between the independent and dependent variables (Path c) becomes insignificant once the mediator is controlled for in the statistical model.

However, experts no longer recommend this method [9]. Indeed, it is not necessary to validate all four conditions to demonstrate a mediational effect, as measuring or testing the significance of the total effect (Path c) is not a prerequisite for mediation. If Paths a and b are significant, it implicitly suggests that Path c is also likely to be significant, even if it is not directly measured [25]. Additionally, a non-significant Path c does not necessarily indicate the absence of mediation; rather, it may result from inconsistent mediation [8, 29]. This occurs when the direct (Path c') and indirect effects (the product of

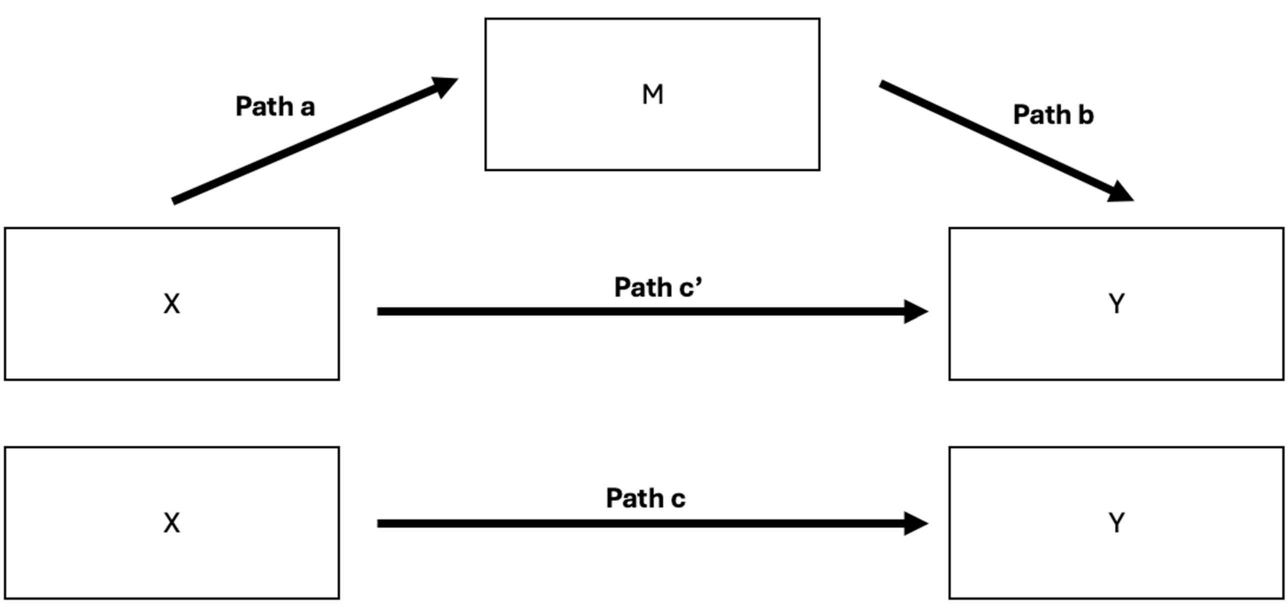

Fig. 1 Causal relationship of the mediation framework

Path a and Path b) have opposite signs, canceling each other out, leading to a null total effect [8, 29] (see *Eq. 1*):

$$Path\ c = \ Path\ c' + (Path\ a * Path\ b) \qquad (1)$$

Regarding the fourth step, a full mediation effect appears when Path c' equals to zero [27, 28]. However, mediation can also be partial, meaning that Path c' remains significant, but its value is lower than that of Path c [25, 29].

In traditional mediation analysis, regressions are calculated [8] and the indirect effect (mediational effect) is obtained via the product approach, which involves multiplying the regression score of Path a by the regression score of Path b [29]. Alternatively, the difference method can also be used, which calculates the indirect effect by subtracting the regression score of the direct effect from the regression score of the total effect [30].

In contrast, the causal inference mediation framework accounts for nonlinear relationships, interactions, and all confounding factors [29]. The total effect comprises both natural direct and indirect effects [29]. However, the scores for direct and indirect effects are not the result of simple regressions, but rather from counterfactual definitions [29]. This means to estimate how the dependent variable (Y) would be impacted when values of the independent variable (X) (for direct and indirect effects) and the mediator (M) (only for indirect effects) are fixed under different conditions (conditional expectations) [29] (*for complete definitions, refer to the cited article*). Moreover, estimating natural direct and indirect effects relies on specific identifiability assumptions (see Fig. 2), which must be met in addition to the statistical significance of Path a and Path b (5): (1) no unmeasured confounding between X and Y, (2) no unmeasured confounding between M and Y, (3) no unmeasured confounding between X and M and (4) no confounding in the M-Y relationship that is influenced by X (not represented in Fig. 2 but could be illustrated by an arrow linking X to $C_{M,Y}$).

Therefore, in causal inference mediation analysis, the indirect effect is not calculated by simply multiplying Path a by Path b, as this assumption is based on the linearity of relationships, which is not considered in the causal inference mediation framework [29].

Study eligibility

Only studies focusing on the association between the living environment and sleep through physical activity - as mediator variable - were included in the systematic review.

Regarding the eligibility criteria for mediation, we included studies that used the traditional method and the causal inferation approach.

The systematic review did not include studies that considered physical activity as a moderating or confounding variable. Unlike the mediating variable, which implies a causal link between the variables, as illustrated in Fig. 1, the moderating variable does not act as an intermediary in the causal relationship [31]. More precisely, it is a variable that influences the relationship between X and Y by altering the direction and/or the strength of their association [27]. Moreover, the confounding variable is not in a causal sequence [31], unlike the mediating variable, even though it is linked to both X and Y [8]. The confounding assumption is based on the idea of adjusting the observed effects to provide an unbiased estimate of the effect of the independent variable on the dependent variable [8]. The distinction between these three third variables will only be possible through the identification of the conceptual framework used in each study included in this systematic

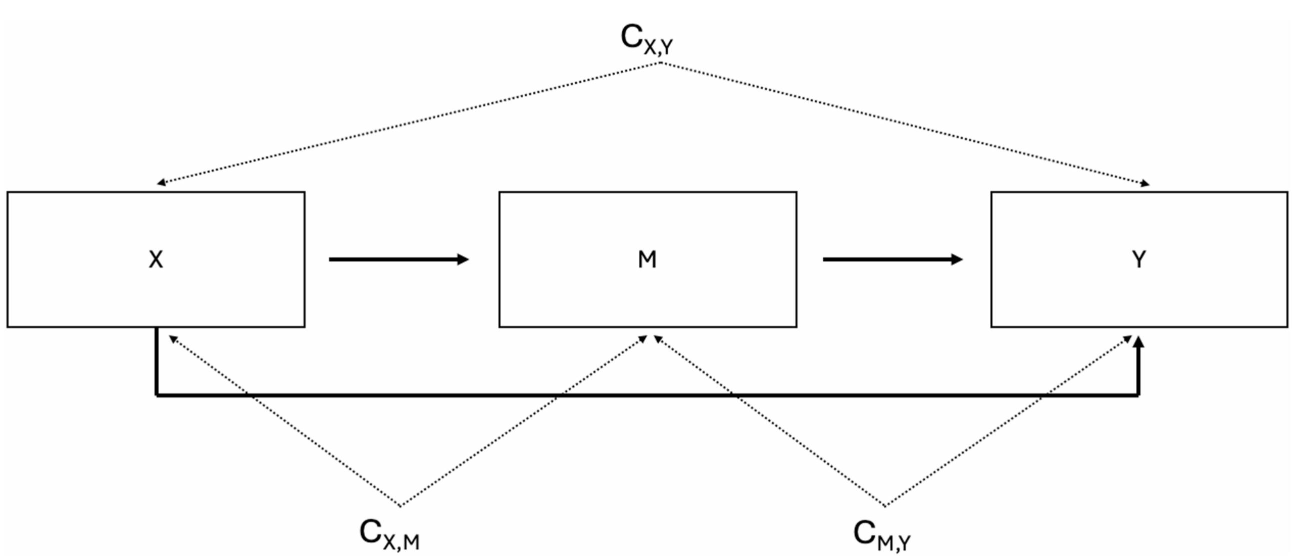

Fig. 2 Identifiability assumptions of the causal inferation mediation framework

review, as there are strong statistical similarities between these three concepts [8].

Finally, only studies (experimental or observational) written in English were included, as this is considered as the language of communication in science [32], and there is no systematic bias in restricting the systematic search to articles written in English [33]. Also, studies involving humans, regardless of age, gender or ethnicity, were all considered. Moreover, case reports and series, qualitative studies, study protocols, preprint articles and conference abstracts were exclusion criteria. All the inclusion and exclusion criteria are reported in Table 1.

Study selection

All studies identified in the different databases were exported to Covidence software, which allows the identification of any duplicates, before the selection of studies was carried out by two independent reviewers (M.S. and O.B.). This selection was first performed on the titles and abstracts of the studies. A selection was then made on the basis of the full-text articles, and the reasons for exclusion were detailed by the two reviewers. Conflicts were resolved by discussion and consensus. Although disagreements can be quantified using a metric such as Cohen's Kappa, which measures inter-rater reliability while accounting for chance agreement [34], this was not calculated during the screening process. This statistic could be applied during the process to refine the eligibility criteria [34]. However, the conflicts were resolved as they arose during the study, rather than at the end, in order to adjust and clarify the inclusion and exclusion criteria iteratively. During the study selection process, the authors of the articles were contacted when there were missing or additional data to be requested.

Table 1 Eligibility criteria

Inclusion criteria
Population: humans regardless of age, gender or ethnicity
Intervention: the association between the living environment and the sleep through the mediation of physical activity. The two types of mediation framework were considered
Outcome: sleep
Study design: experimental (randomized controlled trials, quasi-experimental studies and pre-experimental studies) and observational studies (cohort studies, case control studies and cross-sectional studies)
Language: English publications
Exclusion criteria
Population: animals
Outcomes: physical activity as moderator or confounding variable
Study designs: case reports, case series and qualitative studies
Other publications: study protocols, preprint articles and conference abstracts
Language: Non-English language publications

Data extraction

A draft data extraction form was pretested and then adapted for use by 2 independent reviewers (M.S. and O.B.). The data extracted in each study included the following:

1. Characteristics of the manuscript: first author, title, journal, year of publication.
2. Characteristics of the study: study design, duration (if applicable) of the study and country (and city/region).
3. Characteristics of the population: sample size, gender and ethnicity distributions, age range and target population.
4. Types of outcomes: independent, mediator and dependent variables.
5. Mediation framework used and measures reported.
6. Results: Path a, Path b, indirect effect, total (Path c) and direct effects (Path c') when available, findings and confounding variables.

Risk of bias

The methodological quality of the eligible studies was assessed via the critical appraisal tools for use in JBI Systematic Reviews [35]. A specific tool is available for each study design, consisting of a series of questions that evaluate the risk of bias related to various aspects of the study, such as its design, conduct and analysis. Each item can be rated as "Yes", "No", "Unclear", or "Not applicable". Although these tools do not yield an overall score or classification, they provide valuable information to support the synthesis and interpretation of the study's findings. This assessment was independently performed by two reviewers (M.S. and O.B.), and any conflicts were resolved through consensus. Furthermore, beyond the traditional assessment of study design, it is also possible to evaluate the risk of bias specifically related to mediation. However, according to a recent systematic review, none of the existing tools are optimal due to a lack of validation, consensus-based and rigorous development [36]. Nevertheless, we deemed it important to incorporate certain key elements of mediation into our critical narrative analysis. To this end, guided by the AGReMA statement (reporting guidelines for mediation studies) [37], we selected a set of particularly relevant elements, namely: the assumed causal model and the presence of causal directed acyclic graphs, which require a clear identification of independent variables, mediator, dependent variables and covariates; the confounding assumptions, i.e. whether every potential covariate for each pathway had been accounted for; and, finally, whether the document explicitly described how the indirect effect had been estimated.

Data synthesis

The indirect (mediational) effects were interpreted on the basis of whether the effect was positive or negative and on the type of associations of Path a and Path b [9]. Indeed, an indirect path showing a positive association can result from either positive or negative Paths a and b. An indirect path showing a negative association can result from either a positive Path a and an negative Path b or the opposite [9]. To enhance the clarity of result interpretation, the concept of a total or partial mediator effect was not considered, as some authors argue that it is an outdated notion [9]. The results are presented according to the effect measure chosen by the authors of the included articles.

Due to the heterogeneity observed in the data collected, the results were presented descriptively in narrative form, supported by tables. Given the diversity in methods and outcomes, a meta-analysis could not be undertaken.

Results

Study selection

A total of 2006 studies were identified through searches of the three databases (842 from Scopus, 665 from Embase and 499 from Medline (via PubMed)). After removing duplicates (n = 859), the 1147 remaining studies were screened based on their titles and abstracts. Among these, 141 studies were selected for full-text review, and finally, only 5 studies met the eligibility criteria for inclusion in the systematic review. The Cohen's Kappa was calculated retrospectively for the first (titles and abstracts) and second (full-texts) screenings, yielding values of 0.4608 and 0.5490, respectively. These values indicating moderate inter-rater reliability [38] for the screening process. The studies exclusion criteria are presented in the PRISMA 2020 flow diagram (*see* Fig. 3). Moreover, no additional studies were identified through additional manual searches.

Characteristics of the included studies

All the characteristics of the studies are available in Table 2. Regarding study design, four studies [39–41, 43] were cross-sectional studies and only one [42] was a longitudinal cohort study. Three studies [39, 41, 42] were conducted exclusively in 3 US east coast states (respectively Alabama, Mississippi and Pennsylvania), one study [40] was conducted in 6 US cities and one study [43] included results from 18 countries/regions (see Table 2 for details). The sample size of participants ranged from 231 in the study by Philbrook et al. [39] to 16.077 in the study by Martin et al. [43]. The mean age ranged from 16.75 to 68.5 years (information not available for the study of Martin & Al [43]). All studies included both men and women, although the proportion of women was always greater than that of men. All studies used the concept of sex rather than gender in the classification

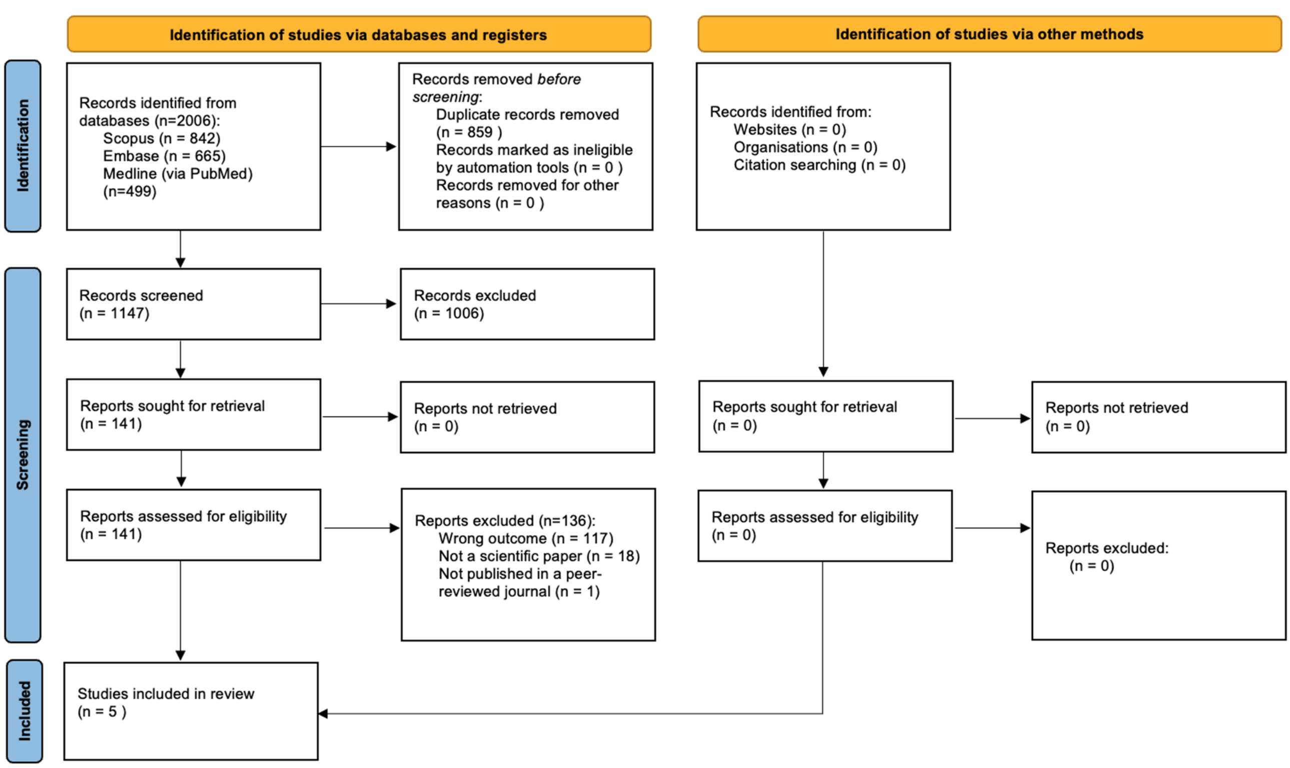

Fig. 3 PRISMA 2020 flow diagram for new systematic reviews which included searches of databases, registers and other sources

Table 2 Characteristics of the included studies

Study	Study design	Country/Region	Sample	Independent variable(s) (IV)	Mediator variable (domain) (MV)	Dependent variable(s) (DV)	Mediation framework used	Measures reported
Philbrook and El-Sheikh, 2016 [39]	Cross-sectional study	Alabama, USA	231 adolescents (M = 16.75 years, SD = 0.81), 55% female, 67% European American – 33% African American	Access to recreational facilities	Physical activity (only leisure activities)	(1) Sleep minutes, (2) wake time, (3) WASO, (4) sleep efficiency	Traditional mediational framework	Total effect (Path c), direct effect (Path c'), effect of IV on MV (Path a), effect of MV on DV (Path b) and indirect effect (product of Path a by Path b)
Billings et al., 2016 [40]	Cross-sectional study	6 US cities (Los Angeles, New York, Chicago, Winston-Salem, St.Paul and Baltimore)	1896 adults, (M = 68.5 years, SD = 9.8), 54.4% female, 35.7% White, 12.2% Chinese-American, 28.4% Black, 23.7% Hispanic	Neighborhood walking environment	Physical activity (each domain)	Obstructive sleep apnea (OSA)	Traditional mediational framework	Total effect (Path c), effect of IV on MV (Path a), effect of MV on DV (Path b) and indirect effect (product of Path a by Path b)
Tamura et al., 2022 [41]	Cross-sectional study	Mississippi, USA	4705 adults, (M = 55.04 years, SD = 12.82), 63.4% female, 100% African American	(1)Violence, (2) problems and (3) social cohesion	Physical activity (transport-related activities, leisure activities and household activities)	(1)Sleep duration, (2) sleep quality, (3) short sleep, (4) long sleep	Traditional mediational framework	Total effect (Path c), direct effect (Path c'), effect of IV on MV (Path a), effect of MV on DV (Path b) and indirect effect (product of Path a by Path b)
Kim et al., 2023[42]	Longitudinal cohort study (repeated measures between 2013 and 2018)	Pennsylvania, USA	1051 (in 2013) adults with low income, (M = 54.6 years, SD = 16.5), 76.4% female, 92% African-American – 8% Non-African American	(1) Urban design, (2) walkability, (3) neighborhood disorder, (4) crime	Physical activity (transport-related activities, leisure activities and household activities)	(1) Insufficient sleep, (2) sleep duration, (3) wakefulness after sleep onset (WASO), (4) sleep efficiency	Causal inference mediation framework	Total effect, natural direct effect, effect of IV on MV (Path a), effect of MV on DV (Path b), natural indirect effect, proportion mediated
Martin et al., 2024 [43]	Cross-sectional study (an 18-country analysis)	18 countries/regions: Bulgaria, California (USA), Canada, Czech Republic, Estonia, Finland, France, Germany, Greece, Hon Kong (China), Ireland, Italy, the Netherlands, Portugal, Queensland (Australia), Spain, Sweden, United Kingdom	16.077 adults, (18.1% for the 18–29 years and the 30–39 years, 18.9% for the 40–49 years, 18.3% for the 50–59 years and 26.6% for the 60 years and over), 50.9% female, 89% not considered as ethnic minority, 7% considered and 4% undisclosed	(1) Green space visits, (2) blue space visits	Physical activity (leisure activities and transport-related activities)	Insufficient sleep	Traditional mediational framework	Total effect (Path c), direct effect (Path c'), effect of IV on MV (Path a), effect of MV on DV (Path b) and indirect effect (product of Path a by Path b)

of sociodemographic characteristics. One study [41] focused exclusively on the African American community, and for another study, the sample was over 90% African American [42]. One was focused mainly on the Caucasian population [39], one included a culturally diverse population [40], and another focused mainly on a sample that did not consider themselves to be an ethnic minority [43]. All studies [40–43] focused on adults, except one [39] which focused on adolescents.

Regarding the independent variables, all studies focused exclusively on neighborhood-level factors (see the *Glossary section* for definitions). Among them, three studies [39, 40, 43] examined only aspects of the physical environment, considering accessibility to recreational facilities, the walking environment, and visits to green and blue spaces. One study [41] focused solely on the social environment, taking into account violence, problems, and social cohesion. Finally, one study [42] explored both physical environment elements (urban design and walkability) and social environment factors (disorder and crime). Among the physical environment factors, walkability has been the most frequently investigated. However, no social environment factor was predominant, as definitions vary among authors.

The mediating variable investigated was always physical activity. Two studies [41, 42] examined all three domains of physical activity: transport-related activities, leisure activities, and household activities. One study focused on leisure activities and transport-related activities [43], whereas another exclusively examined leisure activities [39]. Finally, one study analyzed overall physical activity by assessing total body acceleration via an actimetry device [40]. No study considered work-related activities, and one explicitly excluded them from its assessment of physical activity [43]. Overall, the most frequently investigated type of physical activity was leisure activities.

Concerning the dependent variable, three studies [39, 41, 42] examined sleep duration. Moreover, three studies [41–43] focused on short sleep durations (insufficient sleep), all of which were defined as sleeping less than 6 h per night. One study investigated long sleep duration, defined as 9 h or more per night [41]. Additionally, two studies [39, 42] examined the WASO, and two studies [39, 42] assessed sleep efficiency. One study analyzed wake time [39], another investigated sleep quality [41], and one focused on the apnea-hypopnea index [40]. No study has examined sleep stage distribution, sleep latency, or napping (in terms of duration and frequency).

Regarding the type of mediation framework used, four out of five studies [39–41, 43] adopted a traditional approach. Only the study by Kim et al. opted for a causal inference mediation framework [42].

Associations between the living environment and sleep through physical activity

To facilitate the interpretation of the results (available in Table 3), we first present the indirect effect, followed by the results for Path a (X-M relationship) and Path b (X-Y relationship) (if the indirect effect is significant). A positive effect means that the two variables move in the same direction - if one increases, the other increases too, and vice versa. A negative effect means that the two variables move in opposite directions - if one increases, the other decreases, and vice versa. It should be noted that in the Kim & Al. study [42], the indirect natural effect was not the product of Path a and Path b because they used a causal influence mediation framework. The results for the total effect (Path c) and the direct effect (Path c') are not discussed but are available in Table 3. In addition, the findings are presented according to the type of outcome, namely: sleep duration, short and long sleep duration, WASO and wake time, sleep efficiency, sleep quality and the apnea-hypopnea index.

Sleep duration

Access to recreational facilities [39], neighborhood social cohesion [41] and urban design [42] had *significant positive indirect effect* on sleep duration through physical activity. For the first two living environments items, this occurred because improving access to recreational facilities and strengthen neighborhood social cohesion were associated with more physical activity (respectively: B = 0.20, $p < 0.01$ and B = 0.58, $p < 0.05$), and more physical activity was in turn associated with longer sleep duration (respectively: B = 0.23, $p < 0.01$ and B = 2.44, $p < 0.001$). Regarding the third one, this occurred because better urban design was associated with less physical activity (B= −335, $p < 0.05$), and less physical activity was in turn associated with longer sleep duration (B= −3.62, $p < 0.05$).

Neighborhood violence [41], neighborhood problems [41] and neighborhood disorder [42] had a *significant negative indirect effect* on sleep duration through physical activity. For the first two living environments items, this occurred because reducing neighborhood violence and problems were associated with more physical activity (respectively: B = −0.82, $p < 0.01$ and B = −0.50, $p < 0.01$), and more physical activity was in turn associated with longer sleep duration (respectively: B = 2.41, $p < 0.001$ and B = 2.43, $p < 0.001$). Regarding the neighborhood disorder, this occurred because reducing neighborhood disorder was associated with less physical activity (B = 360, $p < 0.05$), and less physical activity was in turn associated with longer sleep duration (B= −3.62, $p < 0.05$).

There was no significant association between walkability and sleep duration through physical activity [42]. The same was true for crime [42].

Short sleep duration and long sleep duration

Violence and problems in the neighborhood had a *significant positive indirect effect* on short sleep duration through physical activity [41]. More specifically, this occurred because reducing violence and problems in the neighborhood were associated with more physical activity (respectively: B = − 0.87, $p < 0.01$ and B = − 0.52, $p < 0.01$), and more physical activity was associated with a lower risk of short sleep duration (respectively: OR = 0.93, $p < 0.001$ and OR = 0.93, $p < 0.001$).

The same study [41] reported that neighborhood social cohesion had *a significant negative indirect effect* on short sleep duration through physical activity. More specifically, this occurred because strengthen social cohesion was associated with more physical activity (B = 0.68, $p < 0.01$), and more physical activity was in turn associated with a lower risk of short sleep duration (OR = 0.93, $p < 0.001$).

Table 3 Results of the different associations investigated

Study	Mediator variable (MV)	Independent variable (IV)	Path c (Total effect)	Path c′ (Direct effect)	Path a	Path b	Indirect effect	Findings (significant/non-significant indirect effect)	Confounding variables
			Dependent variable(s) (DV)						
Philbrook and El-Sheikh, 2016 [39]	Physical activity (leisures activities)	Access to recreational facilities	Sleep minutes (DV)					The access to recreational facilities had a significant indirect effect on sleep minutes, wake time and WASO through physical activity. No effect on sleep efficiency through physical activity.	Sex, ethnicity, income, BMI
			(B = 0.18*)	(B = not reported but NS)	(B = 0.20**)	(B = 0.23**)	(B = significantly positive but value not reported)		
			Wake time (DV)						
			(B = 0.27**)	(B = 0.21*)	(B = 0.20**)	(B = 0.18*)	(B = significantly positive but value not reported)		
			Wake time variability (WASO) (DV)						
			(B = not reported but NS)	(B = not reported but NS)	(B = 0.20**)	(B = −0.18*)	(B = significantly negative but value not reported)		
			Sleep effiency (DV)						
			(B = 0.15)	(B = 0.15)	(B = 0.20**)	(B = not reported but NS)	(B = not possible to calculate but NS)		
Billings et al., 2016 [40]	Physical Activity	Lowest quartile of neighborhood walking environment	Apnea-hypopnea index (AHI) *of obstructive sleep apnea (OSA)* (DV)					The lowest quartile of neighborhood walking environment had a non-significant indirect effect on OSA through physical activity.	Age, ethnicity, sex, income, education, study site, smoking status, diabetes, hypertension, depressive symptoms, neighborhood socioeconomic status, BMI
			(B = 2.73*)	(B = not reported)	(B = not reported but NS)	(B = −2.40*)	(B = not reported but NS)		
Tamura et al., 2022 [41]	Physical activity	Sleep duration (DV)						Neighborhood violence, problems and social cohesion had a significant indirect effect on sleep duration, sleep quality and short sleep through physical activity. No significant indirect effect for each independent variable on long sleep through physical activity was found.	Age, gender, level of education, income, alcohol consumption, smoking status, BMI, heart attacks, cancers, stroke, diabetes, hypertension, population density
		Neighborhood violence	(B = −5.12)	(B = −3.15)	(B = −0.82**)	(B = 2.41***)	(B = −1.97***)		
		Neighborhood problems	(B = 3.17)	(B = 4.39)	(B = −0.50**)	(B = 2.43***)	(B = −1.23***)		
		Neighborhood social cohesion	(B = −9.23)	(B = −10.65)	(B = 0.58*)	(B = 2.44***)	(B = 1.42***)		
		Sleep quality (DV)							
		Neighborhood violence	(OR = 1.97[1])	(OR = 1.04)	(B = −0.82**)	(OR = 1.10***)	(OR = 0.93***)		
		Neighborhood problems	(OR = 1.99[1])	(OR = 1.04)	(B = −0.50**)	(OR = 1.10***)	(OR = 0.95***)		
		Neighborhood social cohesion	(OR = 2.02[1])	(OR = 0.96)	(B = 0.58*)	(OR = 1.10***)	(OR = 1.06***)		
		Short sleep (DV)							
		Neighborhood violence	(OR = 2.23[1])	(OR = 1.17)	(B = −0.87**)	(OR = 0.93***)	(OR = 1.06***)		
		Neighborhood problems	(OR = 2.04[1])	(OR = 1.00)	(B = −0.52**)	(OR = 0.93***)	(OR = 1.04***)		
		Neighborhood social cohesion	(OR = 2.22[1])	(OR = 1.27)	(B = 0.68**)	(OR = 0.93***)	(OR = 0.95***)		
		Long sleep (DV)							
		Neighborhood violence	(OR = 1.10[1])	(OR = 1.08)	(B = −0.45)	(OR = 0.96)	(OR = 1.02)		
		Neighborhood problems	(OR = 1.10[1])	(OR = 1.09)	(B = −0.32)	(OR = 0.96)	(OR = 1.01)		
		Neighborhood social cohesion	(OR = 2.22[1])	(OR = 1.06)	(B = 0.16)	(OR = 0.96)	(OR = 0.99)		

Table 3 (continued)

Study	Mediator variable (MV)	Independent variable (IV)	Path c (Total effect)	Path c′ (Direct effect)	Path a	Path b	Indirect effect	Findings (significant/non-significant indirect effect)	Confounding variables
Kim et al., 2023 [42]	Physical activity	Insufficient sleep (DV)						The urban design and the neighborhood disorder had a significant indirect effect on sleep duration through physical activity. The urban design had a significant indirect effect on WASO through physical activity. No significant indirect effect for each independent variable on insufficient sleep and sleep efficiency through physical activity was found. No significant indirect effect for walkability and crime on sleep duration through physical activity was found. No significant indirect effect for walkability, neighborhood disorder, crime on WASO through physical activity was found.	Age, sex, income, education, employment status, marital status, vehicle availability, duration of residence in the current neighborhood
		Urban design	(OR = 1.01)	(OR = 1.01)	(B = −355*)	(OR = 1.07)	(OR = 1.00)		
		Walkability	(OR = 0.99)	(OR = 0.99)	(B = −126)	(OR = 1.07)	(OR = 1.00)		
		Neighborhood disorder	(OR = 0.99)	(OR = 0.99)	(B = 360*)	(OR = 1.07)	(OR = 1.00)		
		Crime	(OR = 1.03)	(OR = 1.03)	(B = −70)	(OR = 1.07)	(OR = 1.00)		
		Sleep duration (DV)							
		Urban design	(B = 1.37)	(B = 0.81)	(B = −355*)	(B = −3.62*)	(B = 0.57*)		
		Walkability	(B = −0.67)	(B = −0.86)	(B = −126)	(B = −3.62*)	(B = 0.19)		
		Neighborhood disorder	(B = −2.79)	(B = −2.15)	(B = 360*)	(B = −3.62*)	(B = −0.63*)		
		Crime	(B = 0.68)	(B = 0.61)	(B = −70)	(B = −3.62*)	(B = 0.07)		
		WASO (DV)							
		Urban design	(B = −2.53*)	(B = −2.90*)	(B = −355*)	(B = −3.19*)	(B = 0.37*)		
		Walkability	(B = 1.35)	(B = 1.22)	(B = −126)	(B = −3.19*)	(B = 0.13)		
		Neighborhood disorder	(B = 1.99)	(B = 2.40)	(B = 360*)	(B = −3.19*)	(B = −0.42)		
		Crime	(B = 5.23*)	(B = 5.17*)	(B = −70)	(B = −3.19*)	(B = 0.06)		
		Sleep efficiency (DV)							
		Urban design	(B = 0.91*)	(B = 0.90*)	(B = −355*)	(B = −0.08)	(B = 0.01)		
		Walkability	(B = −0.08)	(B = −0.08)	(B = −126)	(B = −0.08)	(B = 0.01)		
		Neighborhood disorder	(B = −0.77*)	(B = −0.75*)	(B = 360*)	(B = −0.08)	(B = −0.01)		
		Crime	(B = −0.75*)	(B = −0.76*)	(B = −70)	(B = −0.08)	(B = 0.00)		
Martin et al., 2024 [43]	Physical activity	Insuffcient sleep (DV)						No significant indirect effect for green and blue space visits on insufficient sleep through physical activity was found.	Gender, age, long-term illness or disability, level of education, marital status, ethnicity, taking pain medication, income, dog ownership, population density
		Green space visits	(B = not available[2])	(B = not available[2])	(B = 0.1526***)	(B = −0.0014)	(B = −0.0002)		
		Blue space visits	(B = not available[2])	(B = not available[2])	(B = 0.0470***)	(B = −0.0014)	(B = −0.0001)		

Legend: *B* Bêta, *OR* Odds ratio

Significance= *, p-value<0.05, **, p-value <0.01, ***, p-value<0.001, NS, non-significative

[1]Score calculated by the authors of the present systematic review by summing the direct and indirect effect scores, but the significance is unknown

[2]The total effect was not specifically measured for physical activity (total effect = direct effect + indirect effect via well-being + indirect effect via physical activity). The direct effect was not specifically measured for physical activity (well-being and physical activity were both considered in the calculation of this effect).

No associations were found between urban design, walkability, neighborhood disorder, crime, green and blue space visits (although there were positive significant associations between them and physical activity – Path a) and insufficient sleep through physical activity [42, 43]. Regarding long sleep, none of the living environment items of the Tamura et al. study [41] were significantly associated with this sleep outcome.

WASO and wake time One study [42] reported that the urban design had a *significant positive indirect effect* on the WASO through physical activity. In particular, this occurred because better urban design was associated with less physical activity (B= −335, $p < 0.05$), and less physical activity was associated with a higher risk of WASO (B= −3.19, $p < 0.05$).

Access to recreational facilities had a *significant negative indirect effect* on the WASO through physical activity [39]. More specifically, this occurred because improving access to recreational facilities was associated with more physical activity the (B = 0.20, $p < 0.01$), and more physical activity was associated with a lower risk of WASO (B = − 0.18, $p < 0.05$).

No associations were found between walkability, neighborhood disorder, crime and the WASO through physical activity [42].

Regarding wake time, access to recreational facilities had a *significant positive indirect effect* on wake time through physical activity [39]. More specifically, this occurred because improving access to recreation facilities was associated with more physical activity (B = 0.20, $p < 0.01$), and more physical activity was associated with having later wake time (B = 0.18, $p < 0.01$).

Sleep efficiency No associations were found between access to recreational facilities, urban design, walkability, neighborhood disorder, crime and sleep efficiency through physical activity [39, 42].

Sleep quality Violence and problems in the neighborhood had a *significant negative indirect effect* on sleep quality through physical activity [41]. More specifically, this occurred because reducing violence and problems neighborhood were associated with more physical activity (respectively: B = − 0.82, $p < 0.01$ and B = −0.50, $p < 0.01$), and more physical activity was associated with a better sleep quality (respectively: OR = 1.10, $p < 0.001$ and OR = 1.10, $p < 0.001$).

The same study [41] found that neighborhood social cohesion had *a significant positive indirect effect* on sleep quality through physical activity. More specifically, this occurred because strengthen social cohesion was associated with more physical activity (B = 0.58, $p < 0.05$), and more physical activity was associated with a better sleep quality (OR = 1.10, $p < 0.001$).

Apnea-hypopnea index

No associations were found between the lowest quartile of the neighborhood walking environment and the apnea-hypopnea index through physical activity [40].

Risk of bias

The results of the quality assessment of the four cross-sectional studies [39–41, 43] are presented in Table 4. Among the eight criteria assessed, criteria 1, 2, 5, 6, and 8 were met in all or almost all the studies. However, the assessment of criteria 3, 4, and 7 varied across studies. These criteria correspond to the use of valid and reliable methods to measure the exposure variable (i.e., an aspect of the living environment), the use of standardized criteria for the inclusion of participants, and the valid and reliable measurement of outcomes (i.e., sleep-related outcomes), respectively.

Table 4 Results of the JBI assessment for the cross-sectional studies included

Study	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8
Philbrook and El-Sheikh, 2016 [39]	Yes	Yes	Yes	Unclear	Yes	Yes	Yes	Yes
Billing et al., 2016 [40]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Tamura et al., 2022 [41]	No	Yes	Unclear	Not applicable	Yes	Yes	Unclear	Yes
Martin et al., 2024 [43]	Yes	No[a]	No	Yes	Yes	Yes	No	Yes

Legend: [a]The authors used data from the BlueHealth International Survey, where the sociodemographic data are available; however, they selected a sub-sample for which the sociodemographic data are not provided in the article (but after asking them, we received the characteristics of the sample)

Q1: "Were the criteria for inclusion in the sample clearly defined?"

Q2: "Were the study subjects and the setting described in detail?"

Q3: "Was the exposure measured in a valid and reliable way?"

Q4: "Were objective, standard criteria used for measurement of the condition?"

Q5: "Were confounding factors identified?"

Q6: "Were strategies to deal with confounding factors stated?"

Q7: "Were the outcomes measured in a valid and reliable way?"

Q8: "Was appropriate statistical analysis used?"

Table 5 Result of the JBI assessment for the longitudinal study included

Study	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11
Kim et al., 2023 [42]	Not applicable	Not applicable	Yes	Yes	Yes	Not applicable	Yes	Yes	No	No	Yes

Q1: "Were the two groups similar and recruited from the same population?"

Q2: "Were the exposure measured similarly to assign people to both exposed and unexposed groups?"

Q3: " Was the exposure measured in a valid and reliable way?"

Q4: "Were confounding factors identified?"

Q5: "Were strategies to deal with confounding factors stated?"

Q6: "Were the groups/participants free of the outcome at the start of the study (or at the moment of exposure)?"

Q7: "Were the outcomes measured in a valid and reliable way?"

Q8: "Was the follow up time reported and sufficient to be long enough for outcomes to occur?"

Q9: "Was follow up complete, and if not, were the reasons to loss to follow up described and explored?"

Q10: "Were strategies to address incomplete follow up utilized?"

Q11: "Was appropriate statistical analysis used?"

For the only longitudinal study included [42], of the 11 criteria assessed (see Table 5), 6 criteria (3, 4, 5, 7, 8, and 11) received a favorable rating. In addition, criteria 1, 2, and 6 were rated as 'Not applicable'- the first two because the study did not involve categorizing participants into distinct groups, and the third because the study focused on sleep outcomes rather than the presence of a specific pathology.

In terms of narrative appraisal of mediation, while all studies clearly defined their variables within the assumed causal model, only two studies [41, 43] provided a graphical representation to facilitate interpretation. Regarding confounding assumptions, only Kim et al. study [42], who applied a causal inference mediation analysis, explicitly addressed this aspect. However, it was not specified whether the covariates corresponded to $C_{x,\,y}$, $C_{x,\,m}$ or $C_{M,\,Y}$. Tamura et al. [41] and Martin et al. [43] studies reported including all covariates associated with each predictor and outcome, consistent with the principle of confounding assumptions. However, like the Kim et al. study [42], they did not clarify the specific roles of these covariates. Other studies [39, 40] merely listed the variables included in their models. With respect to the statistical method for estimating the indirect effect, three studies [40, 41, 43] explicitly reported using the product method. Kim et al. study [42] specified the natural indirect effect, while Philbrook et al. study [39] did not describe the procedure aside from mentioning the use of Monte Carlo simulation for power analysis. However, it is clear that a traditional approach was applied.

Discussion

To the best of our knowledge, this was the first systematic review on the role of physical activity as a mediator variable in the association between the living environment and sleep. Following a rigorous methodological process, five studies were included. The findings, related to the indirect effects, highlight that improving access to recreational facilities, fostering stronger social cohesion in neighborhoods, and reducing neighborhood violence and problems were indirectly associated with better sleep health outcomes (longer sleep duration, lower risk of short sleep duration and WASO, later wake time and better sleep quality) through the mediation of higher levels of physical activity. However, given the small number of included studies and the heterogeneity between them, these promising mediation findings should be considered preliminary and require confirmatory studies. Also, the results of the study by Kim et al. [42] remain surprising. While the overall indirect effects of urban design and neighborhood disorder on sleep duration seem logical - positive for the former and negative for the latter - the individual X-M and M-Y associations appear inconsistent. Additionally, the positive indirect effect of urban design on the WASO through physical activity raises further questions.

To demonstrate the presence of a mediating (indirect) effect, Path a and Path b have to be significant [25, 26]. Furthermore, the positive or negative associations of the two paths allow us to better understand the links between each outcome.

The first link examined was the associations between the living environment items and physical activity (Path a). Consistent with the literature [14, 44, 45], the findings show that better access to recreational facilities and more visits to green and blue spaces are associated with higher levels of physical activity. Also, the systematic review found a positive association between neighborhood social cohesion and physical activity. A large epidemiological study (n = 64.754) also identified this item as a key factor, particularly among White and Hispanic participants, though not among Asian and Black participants [46]. However, Tamura et al. (included in this systematic review) addressed this gap by demonstrating the same link in a sample composed entirely of African American individuals [41]. In line with a previous study by Tamura & Al [47]., this systematic review found that higher levels of neighborhood violence and problems were associated with lower levels of physical activity. Moreover, one study showed that nonfatal shootings were associated with physical inactivity [48]. Surprisingly, an improvement in the urban design was associated with lower levels of physical activity. However, the WHO recognizes urban design as a key factor in reducing the burden of physical inactivity and encourages cities to implement urban design strategies on the basis of proven tools and measures that have already shown positive results in certain cities (e.g., Lexington (USA), Copenhagen (Denmark), etc.) [49]. These unexpected findings may be due to the low levels of physical activity observed in the study by Kim et al. [42], but they should also be considered as an outlier in the context of the existing literature. They may also be specific to the context of the study: a predominantly African-American population with a low income. Also, we found that an increase in neighborhood disorder was associated with higher levels of physical activity. Although we expected the opposite relationship, a cross-sectional study also revealed a significant positive association between vandalism (a component of neighborhood disorder) and physical activity [50]. The authors suggested that vandalism might be seen as adding value to the neighborhood rather than as a negative factor and that some individuals, particularly gentrifiers, have a greater tolerance for it [50]. It might also be expected that walkability would be positively associated with physical activity, which was confirmed in a narrative review across all age groups [14], but this was not the case. Similarly, crime rates might be expected to be negatively associated with physical activity. However, no significant association was found, contradicting findings from a NHIS study that reported that lower crime rates were associated with higher levels of physical activity [51].

The second link examined is the associations between physical activity and sleep outcomes (Path b). Consistent with the literature, this systematic review highlights the associations between physical activity and sleep [16, 17]. Specifically, increased physical activity was associated with longer sleep duration, a later wake time, improved sleep quality, a lower risk of WASO and a relative lower risk of short sleep duration (significative and non-significative effects obtained). Consistent with our findings, a systematic review on the effects of physical activity on sleep outcomes found that both regular and vigorous exercise were linked to longer sleep duration, although the effect was small [52]. Intensive exercise has also shown a small to moderate benefit in reducing the WASO, whereas regular exercise has been shown to improve sleep quality [52]. However, one study included in this systematic review reported an unexpected association – increased physical activity was associated with higher risk of short sleep duration [42]. Although this is contrary to expectations and the literature [52], it may be explained by the low levels of physical activity observed in this study [42]. Also, physical activity was significantly associated with a lower risk of short sleep duration in the Tamura et al. study [41] (with no effect in the Martin et al. study [43]) but had no effect on long sleep duration. A large 10-year longitudinal study supported the association between regular physical activity and a reduced risk of short sleep duration and, contrary to our findings, also revealed a reduced risk of long sleep duration [53]. In contrast to what was shown in a systematic review [54], our results suggest a potential benefit of physical activity on WASO that should be investigated in future studies. Also, on the basis of existing data (and despite the small effect) [52], we might have expected an increase in physical activity to be associated with better sleep efficiency, but this was not the case.

Our study found that the included studies were of moderate methodological quality. In terms of the quality of mediation, all studies clearly defined the variables and reported the estimation of the indirect effect, with the exception of one study [39]. With regard to covariates, some authors did not specify their selection criteria (confounding assumptions); however, it seems logical that they were chosen based on their potential influence on each pathway ($C_{Xy, Y}$,$C_{X, M}$, $C_{M, Y}$). According to Vanderweele (p.30), including these covariates in traditional models is essential to achieve model robustness comparable to that of causal mediation [55].

There are some strengths in this systematic review. The most important lies in the rigorous methodological process followed throughout the systematic review, which adhered to the PRISMA 2020 Guidelines [18]. The diversity of ethnic profiles in the included studies is another strength. Indeed, observational studies often highlight the overrepresentation of white populations [56]. Having results that encompass various ethnic groups enhances the generalizability of the findings across diverse populations, contributing to the reduction of health disparities [56].

Although this systematic review has several strengths, it also has several limitations. The first limitation is the small number (n = 5) of studies included, which limits the generalizability of the results. Another limitation is that four out of five studies have a cross-sectional design, whereas one study has a longitudinal design. This implies that evolution through time has not been investigated, and that no causal relationship can be deduced, only associations [57]. The inclusion of only quantitative studies and the exclusion of qualitative studies may also introduce bias in the understanding of the mechanism. For example, the inclusion of qualitative studies could provide insights into how individuals perceive the impact of neighborhood social cohesion on their physical activity and how this, in turn, affects their sleep health. All included studies were conducted in high- or upper-middle-income countries, with a predominance of studies from the USA. Therefore, our findings cannot be generalized to low-middle-income and low-income countries. However, the study by Kim et al. [42] focused on a low-income adult population, although it was still within the context of a high-income country. Also, there is a complete absence of data for the pediatric population. This may be due to the school environment, which is an essential component of this group, and was outside the scope of the study. In addition, we defined the "living environment" concept as residential settings only. This decision was made because individuals spend most of their time at home [58], and including school or workplace environments would have introduced additional heterogeneity across studies. However, we acknowledge that excluding school and workplace settings may limit the generalizability of the findings of this systematic review. Also, while the studies by Philbrook et al. [39] and Billings et al. [40] indicate the statistical significance of the paths, they do not provide the corresponding coefficient values for all paths, including indirect paths. This limits the interpretability of their findings, as it prevents readers from assessing the magnitude of the effects. Finally, there is potentially publication bias. While each study included in the systematic review showed some non-significant results, studies that found no significant results may not have been published. This could lead to an overrepresentation of studies with significant findings, potentially skewing the overall conclusions [59].

Importantly, the findings of this systematic review, highlight key points that represent promising directions for future research. First, the five studies included in this review focused exclusively on neighborhood-level aspects of the living environment, with none examining dwelling-level factors. This represents a significant gap, as both the neighborhood and the dwelling contribute to the broader concept of the living environment. As Meghani et al. [60] rightly pointed out, most studies – particularly studies involving older adults - have examined the influence of neighborhood characteristics on physical activity, while the home environment has been largely overlooked. Moreover, to the best of our knowledge, this gap is not limited to older adults but extends to the general population as well. However, qualitative evidence [60] suggests that several home-related factors such as the presence of a garden, stairs, room layout, and dedicated spaces for exercise (e.g., an indoor pool) may influence physical activity. Given the evidence throughout this review showing that physical activity impacts sleep, it is plausible that certain dwelling characteristics could influence sleep indirectly through their effect on physical activity. As no study has specifically addressed this potential pathway, it constitutes a meaningful and unexplored area for future research. Second, the association between urban planning and physical activity requires further investigation, particularly given the unexpected findings observed. Future research should examine this relationship across diverse racial groups, including White and Black populations, to assess its consistency and generalizability. Third, three possible pathways linking the living environment to sleep, including physical activity, have been identified [10, 11]. The other two involve ambient environmental factors and psychosocial aspects. However, none of the studies reviewed, apart from Billings et al. [40], who included depressive symptoms, considered these two other pathways as confounding variables. Furthermore, although Tamura et al. [41] and Martin et al. [43] examined the mediating roles of physical activity and psychosocial factors separately, neither study investigated a model with multiple mediators simultaneously, nor did they explore the potential interactions between them [61]. In this regard, the results extracted from the different studies included in this systematic review, as well as the conclusions drawn from the simple mediation (i.e., physical activity) analysis, should be interpreted with caution, in light of the potential bias arising from interactions between other mediators in the relationship between living environment and sleep. Such interactions can be conducted via statistical methods within the framework of causal inferation mediation [30]. Given the potential mutual influence among mediating variables, future studies would benefit from assessing these interactions to better capture the complexity of the mechanisms at stake. Fourth, the bidirectional relationship between physical activity and sleep [16, 17] warrants closer attention. This relationship could have influenced the physical activity scores, as they may be affected not only by a factor of the living environment but also by sleep status itself, making the interpretation of the indirect effect more complex and potentially not reflecting reality. This may have biased the results, highlighting the need for caution when interpreting these unidirectional findings. Given the existence of this bidirectional association, it would be interesting to take it into account in future analyses.

In conclusion, this systematic review highlights that physical activity mediates the relationship between access to recreational facilities, neighborhood social cohesion, neighborhood violence and problems with various sleep-related health outcomes. However, although physical activity appears to be a potentially promising mediator in the relationship between certain aspects of the living environment and certain sleep outcomes, the number (n = 5) of studies on this topic remains relatively limited. In addition, each study included in this systematic review focused on a different aspect of the living environment, such heterogeneity limits the comparability of the results. Also, the predominance of cross-sectional studies restricts the ability to examine the temporal dynamics of the findings. As a result, the associations identified should be interpreted with caution and considered as preliminary and hypothesis-generating rather than confirmatory. Therefore, they cannot be used alone as specific recommendations. Instead, they should pave the way for future confirmatory studies - preferably longitudinal and interventional - using a rigorous mediation methodology in line with the AGReMA statement [37]. In addition, future research should consider multiple aspects of the living environment, including dwelling level factors alongside neighborhood-level characteristics.

Abbreviations

M	Mediator variable
PICOs	Population – intervention - comparator – outcomes – study designs
WASO	Wake after sleep onset
X	Independent variable
Y	Dependent variable
PRISMA	The Preferred Reporting Items fo Systematics reviews and Meta-Analyses

Glossary

Access to recreational facilities	the measure of availability of places where someone may engage in exercise such as swimming pools, running tracks or basketball courts (according to the definition by Philbrook et al., 2016 [39]).
Crime	"the total number of recorded crimes occurring within ¼-mile network buffer around each participant's address" (Kim et al., 2023, p738 [42]).
Green and blue spaces	green spaces include areas such as local parks and woodlands, whereas blue spaces correspond to lakes and beaches (according to the definitions by Martin et al. 2024 [43]).
Neighborhood disorder	"adverse physical conditions for each street segment, such as the presence of litter on the street, vacant lots or housing, bars on windows, and broken windows" (Kim et al., 2023, p738 [42]).
Neighborhood problems	concept that includes "neighborhood noise, lack of access to food stores/shopping, lack of adequate access to parks/playgrounds, trash/litter, heavy traffic/speeding cars, no sidewalks/poorly maintained sidewalks" (Tamura et al., 2022, p3 [41])
Neighborhood violence	concept that includes "neighborhood fights with a weapon, gang fights, sexual assaults/rape, violent arguments, and robbery" (Tamura et al., 2022, p3 [41]).
Social cohesion	concept that includes "trust in neighbors, willingness to help neighbors, shared values with neighbors, and extent to which neighbors do not get along" (Tamura et al., 2022, p3 [41]).
Urban design	concept that includes 3 characteristics namely:"(1) the presence of public/street art, (2) landscaping, including the presence of small gardens and planters and (3) neighborhood signage" (Kim et al., 2023, p738 [42]).
Walkability	concept that includes "the presence of traffic lights and signs at intersections, pedestrian crossings, sidewalk conditions (e.g., the presence of sidewalks, sidewalk buffer, continuous sidewalks, and tree shading), street lighting, public transit amenities (e.g., bus stops, and light rail stops), and mixed land use" (Kim et al., 2023, [42]) (no definition provided for the article by Billings et al., 2016, [40]).

Supplementary Information

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Supplementary Material 1

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Author contributions

Conceptualization: MS and OB. Methodology: MS, CE, VT, GS, SA, CS, NB, OB. Data collection and analysis: MS and OB. Manuscript preparation: MS with supervision from OB. All the authors have read and approved the final manuscript.

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Data availability

As this is a systematic review, all the data come from the articles of the authors included in the review and are therefore available on the websites of the journals that published them.

Declarations

Competing interests
The authors declare no competing interests.

Ethics approval and consent to participate
As this was a systematic review, ethics committee approval was not needed. The same applies to consent to participate and consent to publish.

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